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BBC Receiving terminal for the European orbital test satellite

C. Gandy, B.Sc.

**BBC RECEIVING TERMINAL FOR THE EUROPEAN ORBITAL
TEST SATELLITE**

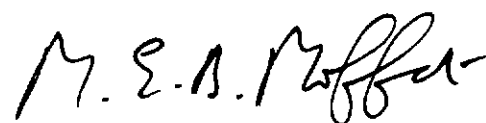
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Summary

A receiving terminal was designed and constructed for reception of frequency-modulated television signals in the 11 GHz band from the European Orbital Test Satellite. The design featured a 2.44m parabolic reflector antenna with a Cassegrain feed employing a corrugated horn, a GaAs f.e.t. low noise amplifier and a tunable, dual-conversion receiver. Provisions were included for reception of the accompanying sound signals, either as sound-in-syncs or on a modulated subcarrier.

The terminal has been used for demonstration purposes and for monitoring television tests which have been performed using the satellite. These have included conventional point-to-point link tests, simulations of Direct Broadcasting by Satellite and commissioning of the BBC Transportable Satellite Earth Station.

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BBC RECEIVING TERMINAL FOR THE EUROPEAN ORBITAL TEST SATELLITE

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1. Introduction

From the launch of the European Orbital Test Satellite (OTS) in 1977 until the end of its useful life in 1983, it was used regularly for relaying frequency-modulated television signals between earth stations for testing and demonstration of equipment for subsequent use in the European Communications Satellite (ECS) system, for ad-hoc programme service operations, and for tests which simulated the conditions of Direct Broadcasting by Satellite (DBS).

The provision of a receiving terminal for the OTS at Research Department was planned shortly after the launch of the satellite when the value of a satellite link was foreseen for test and demonstration purposes. The report describes in detail the design and construction of a small receiving terminal which has been used successfully for several years to receive a variety of signals from the OTS.

2. Requirements of the receiving terminal

The aims of the project were:-

- (a) to maximise the quality of the received television signals with respect to noise and distortion, and

- (b) to provide the greatest utility in receiving different types of signal at different frequencies in the (11 GHz) OTS down-link band.

The use of an r.f. low-noise amplifier and an adaptable, tunable receiver was envisaged. The specific design requirements are summarised in Table 1. Additionally, the receiving terminal was required to operate continuously, unattended, and to provide test facilities for checking its performance.

3. OTS Down-link frequency plan

The principal components of the OTS 11 GHz down-link are shown in Fig. 1 with their corresponding frequencies, polarisations and satellite transmit antennas.

In this context, channels 4 and $\bar{4}$ were most important because the higher gain of the spotbeam antenna meant that the transmitted e.i.r.p. was sufficient for television signals of adequate quality to be received by small earth stations. The spotbeam antenna used dual, orthogonal, linear polarisations for the 4 and $\bar{4}$ transponders, which had very similar characteristics: 120 MHz bandwidth centred on 11.64 GHz. A typical f.m. television signal would occupy 27 or 36 MHz of

TABLE 1 : Design requirements for the terminal

Frequency range	11.45 – 11.85 GHz
Figure of merit (gain/noise temperature)	$\geq 19 \text{ dBK}^{-1}$ for 99.9% of time* (19.4 dBK^{-1} in clear weather)
Antenna polarisation	dual linear
Modulation capability	f.m. (<13.5 MHz to >25 MHz peak deviation [†])
Television standard	625 lines, 50 Hz, PAL
Sound system	sound-in-synchs or f.m. subcarrier

* See Appendix 10.2

† To include DBS and standard Eurovision operating conditions, summarised in Appendix 10.1.

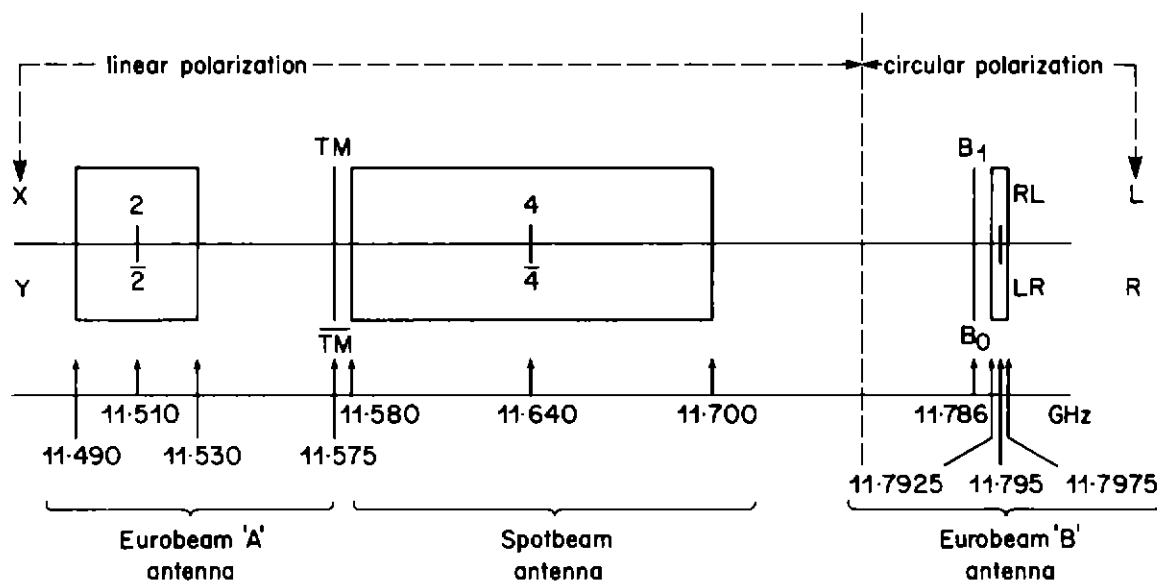


Fig. 1 — The OTS down-link frequency plan.

this bandwidth and although a channel-centre frequency of 11.64 GHz was often used, for various reasons such as co-channel interference (from and to signals in the orthogonally polarised transponder), this was not always the case, so receiver tuning over the 120 MHz bandwidth was required.

The channels 2 and $\bar{2}$ transponders, of which only the former was operational, occasionally carried f.m. television signals, but the lower gain of the Eurobeam 'A' antenna precluded satisfactory reception with small earth stations.

The B₀/B₁ circularly polarised beacons were transmitted by the low gain Eurobeam 'B' antenna (similar to Eurobeam 'A'). They were useful for antenna alignment and an indication of propagation conditions because they used c.w. signals which could be examined using a spectrum analyser adjusted for low bandwidth.

The TM/ $\bar{TM}$ linearly polarised telemetry beacons could be used for antenna polarisation alignment during periods when the f.s.k. telemetry modulation was not present.

The channels RL and LR circularly polarised transponders had 5 MHz bandwidth and carried experimental data signals.

4. Design philosophy

4.1. The antenna

Financial constraints dictated the use of a surplus 2.44m (8 ft.) diameter parabolic reflector

which had previously been used in a BBC terrestrial microwave link. The task was then to apply a feed system to this reflector in such a way as to maximise the aperture efficiency of the antenna and hence the figure of merit (G/T) of the terminal.

The reflector was manufactured for use at lower frequencies, probably 7 GHz, and its surface profile was rather rough for use at 11 GHz. The largest error was caused by annular ripples from the spinning process of manufacture, and measurements showed a peak deviation of ± 1.3 mm from a true paraboloid, measured normal to the reflector surface. From the work of Ruze¹, the reduction of antenna gain caused by this deviation was predicted to be about 0.5 dB. Modern 11 GHz reflectors, of the same diameter, generally deviate by less than ± 0.5 mm peak from the required profile, corresponding to less than 0.1 dB loss.

The OTS was kept within $\pm 0.1^\circ$ of its nominal station² of longitude 10° E in the geostationary orbit (although towards the end of its life it was re-stationed at 5° E). The -1 dB beamwidth of a 2.44 m dish antenna at 11 GHz is about $\pm 0.5^\circ$ so tracking was unnecessary, and a fairly modest, fixed mounting structure would suffice, with manual fine adjustment of the antenna azimuth and elevation.

A Cassegrain feed system was chosen because it offers greater flexibility in the design of the feed, lower losses in connecting waveguides (unless a miniaturised front-end is used at the focus of the reflector), and the (limited) ability to control the aperture illumination. In previous work using the same reflector³ a simple prime-

focus feed system was used with lengthy waveguides. In that case the receiver front-end used a relatively high noise temperature mixer (about 1000K), but the present design called for minimum waveguide loss for the full advantage of a low-noise amplifier to be realised.

Frequency re-use by dual polarisation in the satellite down-link meant that cross-polar discrimination (x.p.d.) was important in the antenna design, and largely for this reason a corrugated conical horn⁴ was chosen for the feed. Also, the fields in the aperture of a corrugated horn operated under balanced hybrid-mode conditions⁵ are symmetrical and very similar to the fields in the focal region of a reflector antenna. The subreflector in the Cassegrain system effectively increases the focal length of the main reflector and decreases the angular aperture presented to the feed, but does not necessarily change the spherical nature of the wavefront which arrives at the feed.

The radiation pattern of a corrugated horn has a main lobe shape similar to the Gaussian "bell", and although this is not the ideal ($\sec^2$) illumination function for a paraboloid, a respectable aperture efficiency (60-70%) is achievable with an optimised design using classical conic sections for the reflector profiles. Special profile shaping processes have been described by Collins⁶ and Wood⁷ which can provide near-ideal illumination, and a useful increase in the aperture efficiency when the subreflector alone is modified. However, these are lengthy numerical processes and development of the necessary computer software was beyond the scope of this project.

In a Cassegrain system there are fundamental trade-offs between:-

- (a) efficient illumination of the aperture and spillover past the rims of the main reflector and subreflector, and
- (b) blocking of the main reflector aperture by the subreflector and blocking of fields between the main reflector and the subreflector by the feed horn aperture.

With a corrugated horn feed, the optimum edge illumination taper for a paraboloid is about 10 dB⁸, and by specifying the diameter of the subreflector all other design parameters can be derived for equal blocking in (b) above. Because geometric optics principles⁹ were used in the design, the subreflector diameter was made as large as possible, consistent with a tolerable loss due to

aperture blocking.

The final design used a hyperboloidal subreflector, 320 mm in diameter, with edge tapers of about 10 dB in the illumination of both reflectors. The predicted aperture blocking loss, using geometric optics, was about 0.2 dB, including the effect of the subreflector supporting struts.

A suitable corrugated horn was designed along the lines of a version described by Clarricoats and Saha⁴, with a 10 dB beamwidth of 28° (the angular aperture of the Cassegrain system). The flare of the horn was lined with conventional $\lambda/4$ deep annular grooves, several per wavelength along the axis of the flare. The transition from smooth-walled to corrugated waveguide, in the throat of the horn, was lined with deeper grooves approaching $\lambda/2$ depth, to improve the impedance match. The process¹⁰ provides a gradual transition between the two types of waveguide which have different phase-velocities.

The x.p.d. of such a horn could be expected to be at least 40 dB over the required 7% bandwidth provided that care was taken in its fabrication to obtain the correct corrugation depths, and to ensure axial symmetry. For the complete antenna, the x.p.d. would be considerably less owing to cross-polarisation caused by the main reflector and the subreflector support struts, to the extent that the cross-polarisation due to the horn would probably be insignificant. The spotbeam transmitting antenna on the OTS had an x.p.d. specification of 30 dB¹¹.

For the complete antenna, the overall aperture efficiency predicted by geometric optics was about 68%, including losses caused by spillover, non-uniform illumination, reflector surface deviation and feed/subreflector blocking. In practice this would be further reduced by aperture phase errors, cross-polarisation, and diffraction effects not accounted for by geometric optics, so a target figure of 60% was considered feasible. Loss in the feed horn and connecting waveguides are not included in this aperture efficiency but are accounted for separately in the final link budget calculations of Appendix 10.2, because they introduce an additional noise temperature contribution.

A 2.44 mm circular aperture antenna, with 60% aperture efficiency, has a gain of 47.2 dB at 11.64 GHz.

4.2. The receiver

Having determined the antenna gain, the

largest remaining factor in the G/T of the terminal was the noise temperature of the receiver front-end. Progress in the manufacture of GaAs f.e.t. amplifiers by the electronics industry indicated that this type of low-noise amplifier (l.n.a.) would be suitable choice regarding noise temperature versus cost. At the design stage in this project, the lowest noise temperature offered by a British manufacturer for a GaAs f.e.t. — l.n.a. operating at room temperature with the required gain, bandwidth and input configuration was 422K (corresponding to a noise figure of 3.9 dB); this type of amplifier was used.

To realise the benefit of the l.n.a. the losses in preceding waveguide components had to be minimised. This was achieved by designing the receiver front-end as an outdoor unit to be mounted very close to the antenna feed, and by minimising the number of flange connections in the waveguide system. In addition the noise figure of the following stages of the receiver had to be made sufficiently low not to degrade significantly the noise performance of the cascaded chain.

A dual-conversion heterodyne receiver was chosen so that the full 120 MHz bandwidth of channels 4 and $\bar{4}$ could be covered by tuning one of the local oscillators, without the need for tunable or switched filters, and with adequate rejection of image-frequency noise. The receiver frequency plan is illustrated in Fig. 2. In addition to the image rejection requirement, the choice of the first i.f. (i.f.₁) was also influenced by the cost of suitable co-axial cable for the link between the antenna site and the laboratory, where the remainder of the receiver was to be sited.

The choice of second i.f. (i.f.₂) was influenced by the type of f.m. demodulator which would be used to cater for the wide (36 MHz) channel bandwidth used in standard Eurovision operating conditions (see Appendix 10.1). Because of the smaller fractional bandwidth, a demodulator operating at 140 MHz offers a significant performance/cost advantage compared with one for the commonly used 70 MHz. Also, with a high second i.f., the receiver could be tuned over a range of 120 MHz at the second frequency conversion without difficult filtering problems, and this would allow the use of a fixed-frequency first local oscillator. Therefore a second i.f. of 140 MHz was chosen.

The optimum choice of first local oscillator was a proprietary phase-locked oscillator; this type offers high stability and low phase-noise, and uses a transistor oscillator with a co-axial

line resonator operating at about 1 GHz, followed by a frequency multiplier. The oscillator is phase-locked to a crystal-controlled reference in the vicinity of 100 MHz.

For the second, tunable local oscillator, a phase-locked transistor oscillator was again specified, but in this case the phase-locked loop was configured as an indirect frequency synthesiser. Such a combination of local oscillators would yield a frequency stability entirely adequate for f.m. television reception without the need for additional automatic frequency control (a.f.c.).

Two second i.f. filters were included in the design, to provide correct receiver bandwidths for f.m. signals employing both DBS and Eurovision operating conditions. The disadvantage of the high second i.f. was the difficulty anticipated in the construction of group-delay equalisers for the i.f. filters. Conventionally, such devices employ a cascade of all-pass sections, but at 140 MHz the effect of stray reactances and coupling could lead to marked differences between predicted and actually required component values. At the design stage of this project, group-delay measuring equipment for 140 MHz was not a laboratory facility and so equalisers were omitted from the design. Provisions were made for their inclusion at a later date.

The audio and video baseband systems were designed for versatility, catering for sound-in-syncs (s.i.s.), f.m. subcarrier sound (on any one of four frequencies), different levels of video and energy dispersal signals, and inverted video (negative modulation).

Test outputs were included in the design, at several points in the receiver signal path, to simplify alignment and testing, and to allow operation with television signals other than 625-line PAL.

5. Description of the receiving terminal

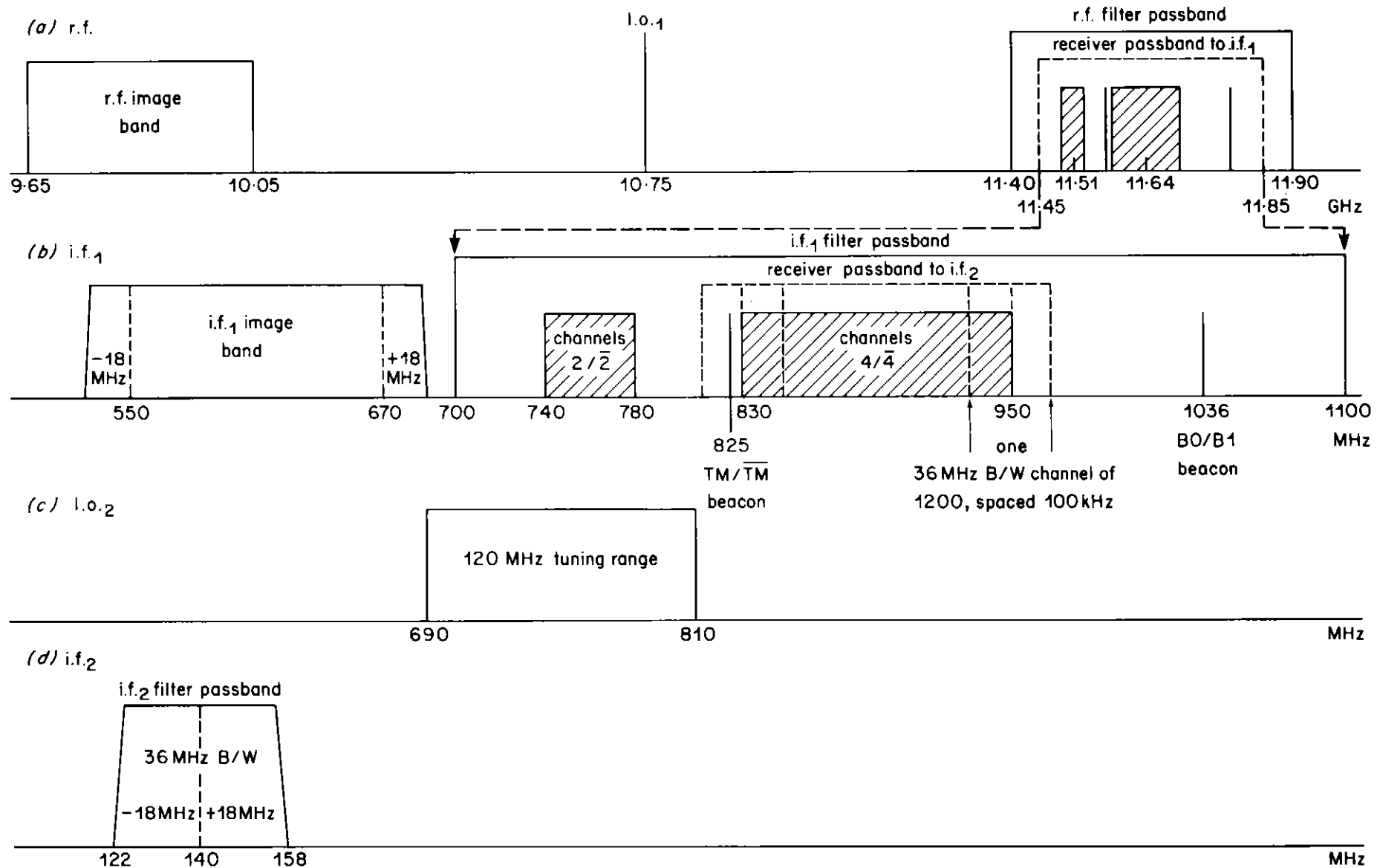
The terminal comprises six functional blocks, as shown in Fig. 3, located at the outdoor antenna site and in the laboratory. The outdoor components were designed for continuous, unattended operation.

5.1. The antenna

The parabolic reflector antenna with its Cassegrain feed system is shown in Fig. 4.

The main reflector was mounted on a

Fig. 2 - The receiver frequency plan.



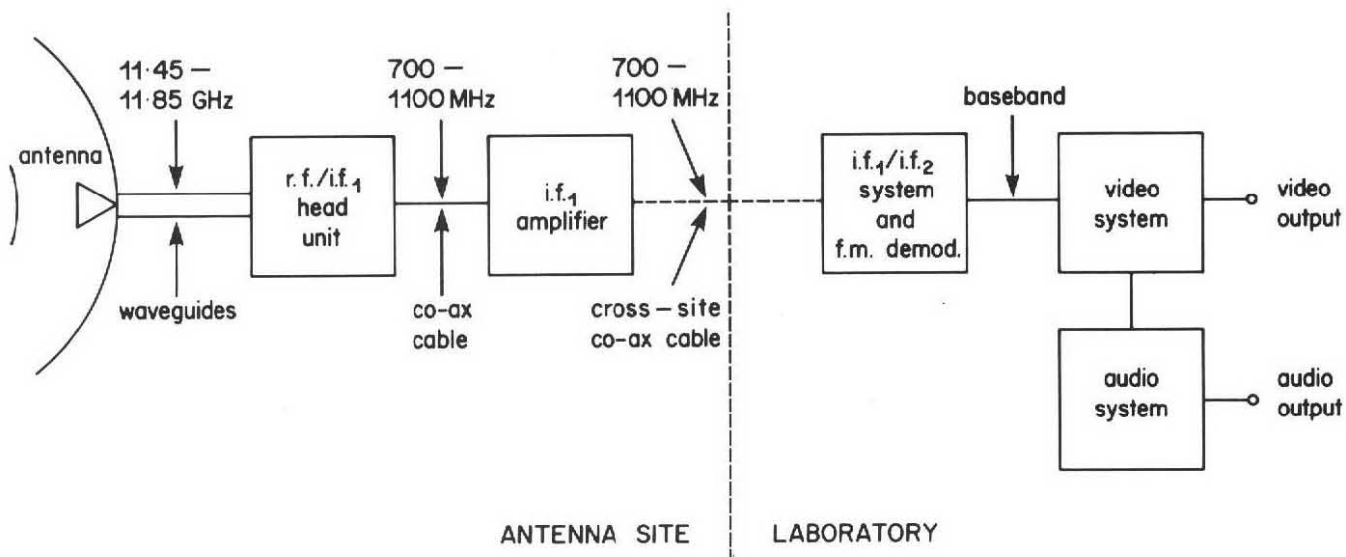


Fig. 3 — Functional-block diagram of the terminal.



Fig. 4 — The reflector antenna.

concrete base with a tetrahedral framework of steel angle. A leadscrew and nut provided the fine elevation adjustment and bottle screws, in opposing tension, allowed fine azimuth adjustment.

The subreflector was supported by four aluminium-alloy tubes which converged to a threaded block. A threaded stud connected this block to the centre boss of the subreflector, allowing fine axial adjustment of its position. The subreflector was formed by spinning a 1.5 mm thick aluminium sheet against a mandrel cut to a hyperbolic profile, on a lathe, using a non-metallic roller. The centre boss was conically shaped on the reflecting side of the subreflector in an attempt to control back-scatter between the horn and sub-reflector, and hence the antenna v.s.w.r.

The feed horn, illustrated in Fig. 5, had a half-flare angle of 12° and a mouth diameter of 130 mm. It was fabricated in three sections to

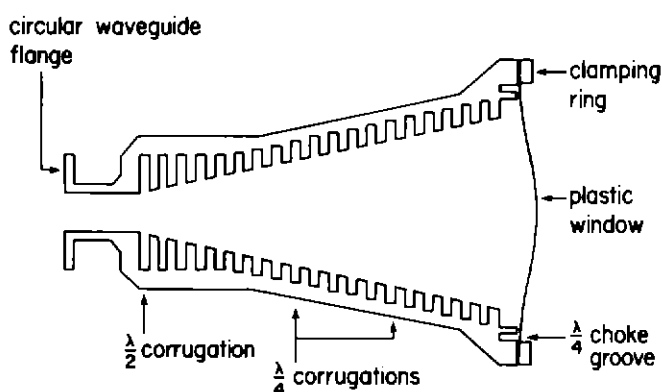


Fig. 5 – The corrugated feed horn.

facilitate cutting of the internal corrugations. An additional $\lambda/4$ deep choke groove was cut around the horn aperture, parallel to its axis, to reduce coupling to the pressure-window clamp ring. The horn was supported at the focal point of the reflector system by a thick-walled alloy tube, through which the connecting circular waveguide passed, and this tube was supported from the vertex of the paraboloid by a substantial alloy cone. The axial position of the horn could be adjusted by sliding the tube through the cone; this was necessary because the location of the horn's phase centre was not previously determined.

The circular waveguide terminated in an orthogonal-mode transducer (o.m.t.), mounted behind the main reflector vertex. Two 450 mm long flexible-twistable waveguides (WG 16) coupled on o.m.t. to the receiver front-end unit, which was mounted on the steel angle framework.

The horn, waveguides and front-end unit are shown, separated from the antenna, in Fig. 6.

The horn and waveguides were pressurised with dry nitrogen at a pressure of 3.5 K Pa (0.51 lb.in^{-2}) to eliminate condensation and consequent corrosion. At this low pressure, a thin polyester window could be used at the horn mouth.

5.2. The receiver

The internal arrangement of the front-end unit is shown in Fig. 7. The i.f.₁ amplifier, to overcome the loss of the cross-site cable, was located in a nearby hut also housed the mains power supply for the front-end unit. This amplifier unit is shown in Fig. 8. The i.f.₁/i.f.₂ conversion system, synthesiser, f.m. demodulator, and the audio and video baseband systems are shown in Fig. 9, assembled with the companion s.i.s. decoder.

A detailed block diagram of the receiver is shown in Fig. 10, and is largely self-explanatory; brief details of some of the more interesting components are given below.

- (a) The 11.4-11.9 GHz band-pass filter, following the l.n.a., used three iris coupled, rectangular waveguide cavities, and exhibited low pass-band insertion loss. Its main purpose was to reject l.n.a. noise in the 9.65-10.05 GHz image band.
- (b) The 700-1100 MHz band-pass filter following the first frequency conversion was of an air dielectric, interdigital form, again for low insertion loss and rapid increase of attenuation into the stop-bands to reject noise in the second-conversion image band.
- (c) The 690-810 MHz frequency synthesiser used a varactor-tuned, co-axial line, fundamental-mode transistor oscillator which was phase-locked, by digital circuitry, to a 10 MHz reference crystal oscillator. The signal frequency range 11.58-11.70 GHz (OTS channels 4/4) was covered in 100 kHz increments and the synthesiser was programmed by thumbwheel switches which displayed the received signal frequency.
- (d) A microstrip band-stop filter was placed after the second conversion mixer to reject the local oscillator (synthesiser) leakage component which might otherwise have compromised the performance of the following amplifier. Wherever practical,

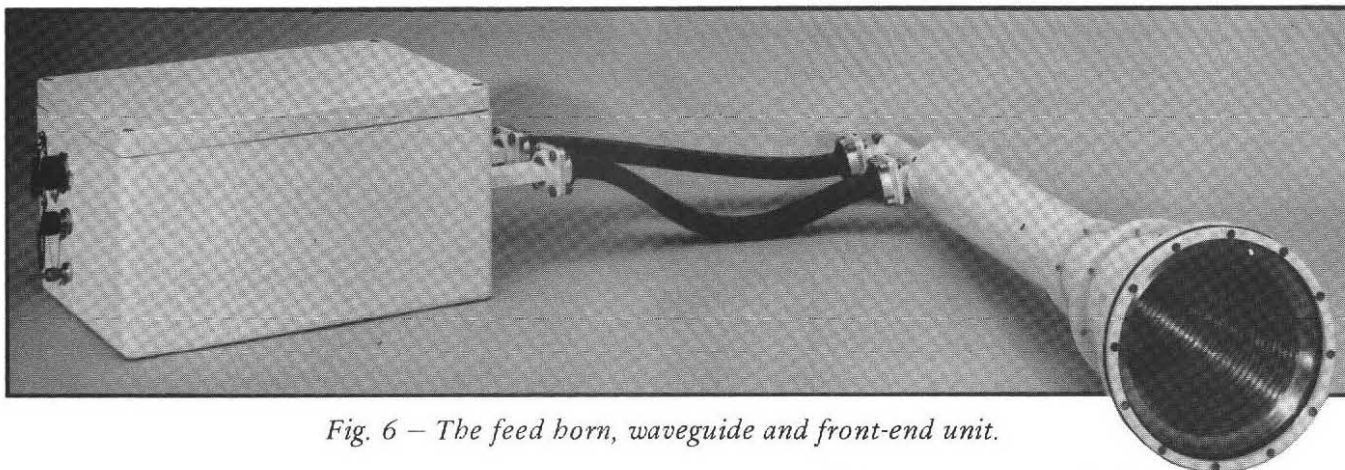


Fig. 6 – The feed horn, waveguide and front-end unit.

amplifiers were used at the input and output ports of the band-pass filters to provide good impedance matches.

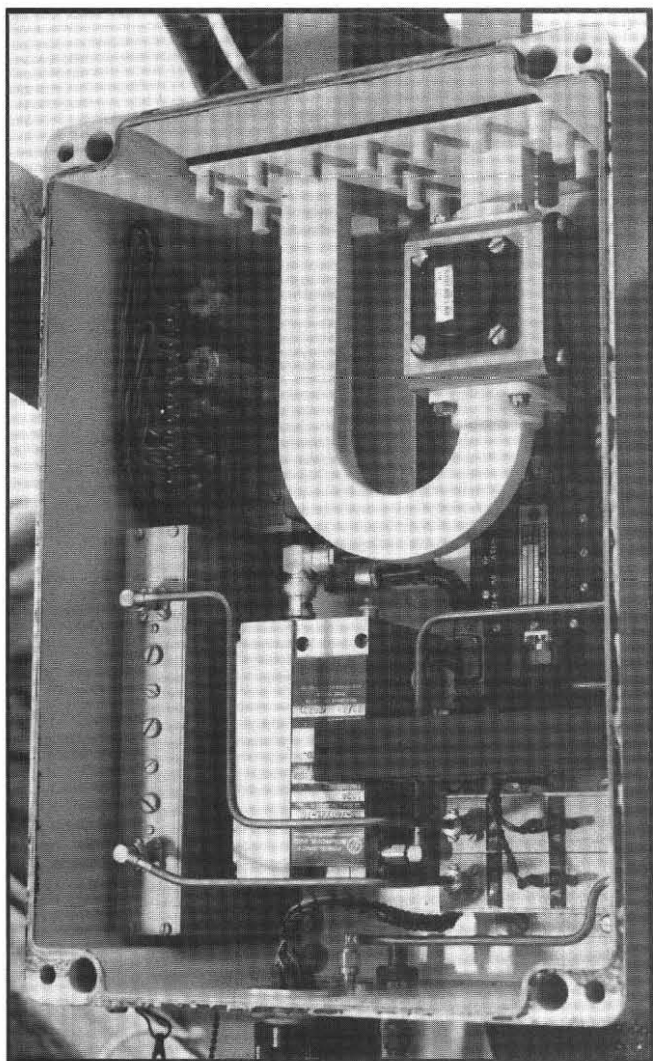


Fig. 7 – Internal arrangement of the front-end unit.

- (e) The channel-defining 140 MHz band-pass filters used discrete components. The 36 MHz one was designed for a Tchebychev response, and the 27 MHz (DBS) one was designed for a Butterworth response.
- (f) The automatic gain control (a.g.c.) amplifier had 20 dB of control range and facilities for signal-level metering. All the i.f. amplification stages used proprietary thin-film cascable amplifier devices. Lower noise figure devices were used where necessary to limit the overall noise figure of the cascaded chain.
- (g) The use of a black-level clamp before the s.i.s. decoder was necessary because the level of 25 Hz energy-dispersal signal required with Eurovision operating conditions exceeded the input specification of the s.i.s. decoder with respect to l.f. ripple. The sync. separator driving the clamp used light a.c. coupling to reject this ripple. A s.i.s. digit blanker was also included to output a clean video signal for test purposes.
- (h) The f.m. sound subcarrier demodulator was fed via a frequency converter so that a subcarrier on any one of four frequencies could be received. The subcarrier frequencies, 6.0, 6.5, 7.0 and 7.5 MHz, were determined by a switched crystal-controlled oscillator

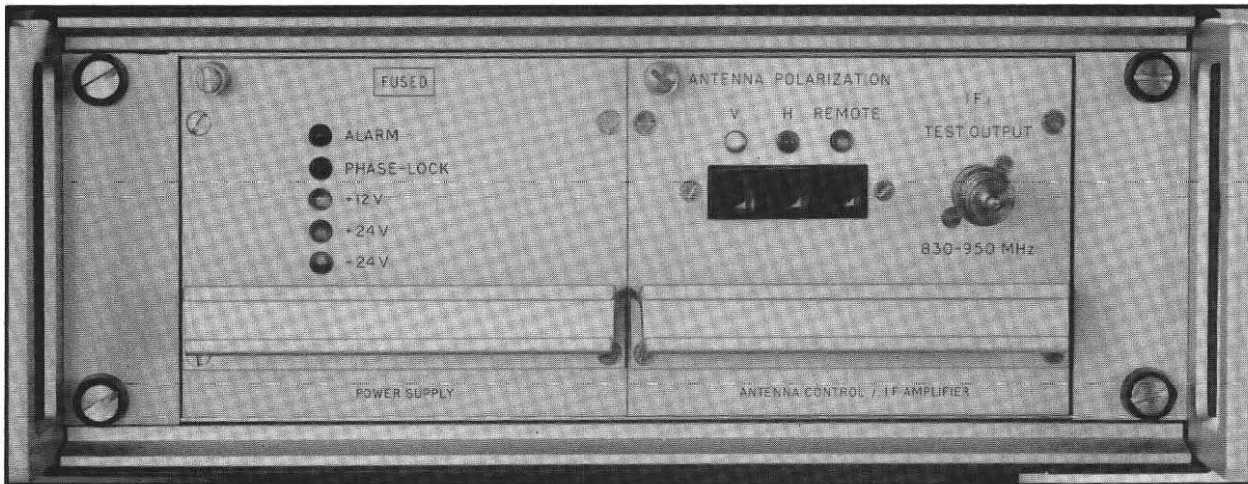


Fig. 8 — The i.f. amplifier and power supply unit.

6. Performance

6.1. The antenna

The feed horn was tested in an anechoic antenna range* at spot frequencies between 10.0 and 15.0 GHz. Far-field radiation patterns were measured, co-polar in the E and H planes, and cross-polar in the 45° plane. The co-polar patterns showed good axial symmetry with less than 1 dB difference between the E and H plane responses over the -10 dB beamwidth. The -10 dB beamwidth was 27° at 15.0 GHz, and this varied by less than ±3° over the range 11.2 to 12.0 GHz. The cross-polar lobes were around -40 dB relative to the co-polar peak, and the return loss measured at the circular waveguide flange of the horn was better than 26 dB in free-field conditions.

Radiation pattern measurement of the complete reflector antenna was not practical because of the long far-field range required for accuracy ($2D^2/\lambda = 460$ m), the lack of suitable towers to overcome the effect of ground reflections, and the limitations of available antenna positioning equipment. The only feasible measurements were first sidelobe level and boresight x.p.d. with antenna mounted and pointing at the satellite. Using the $\overline{\text{TM}}$ linearly polarised beacon, the first sidelobe level was found to be -17 dB relative to the main lobe peak in the azimuth and elevation planes. The boresight x.p.d. was around 25 dB, although this measurement was subject to the accuracy with which the feed polarisation could be set.

The first sidelobe level predicted by numerical aperture field integration, using the measured horn patterns, was -21 dB. This computation accounted for aperture blocking by the subreflector but not its struts, and did not consider aperture phase errors caused by the main reflector profile. The cross-polar performance was not predicted, but in this case a co-channel interference ratio of about 25 dB, though not ideal, was considered usable for television reception on OTS which would not always be fully loaded.

The return loss of the complete antenna system was measured at the rectangular waveguide ports of the o.m.t.; in the frequency range of interest the minimum return loss was 18 dB for both ports. The isolation between the rectangular waveguide ports of the o.m.t. was at least 30 dB.

Gain reduction and de-pointing owing to wind or vibration induced movement was not measurable.

6.2. The receiver

Individual stages of the receiver chain were checked for gain, noise and frequency response by injecting signals into the chain and observing the relevant outputs on a spectrum analyser. The effective input noise temperature of the complete receiver was measured using a noise diode and calibrated attenuators, observing the i.f. signal prior to the a.g.c. amplifier. The performance of the r.f. and i.f. stages was then measured with swept-frequency signal generators and detectors. A summary of the results is shown in Table 2.

With the receiver assembled and connected to the antenna, the performance of the system

* At the Department of Electrical Engineering, Queen Mary College, London.

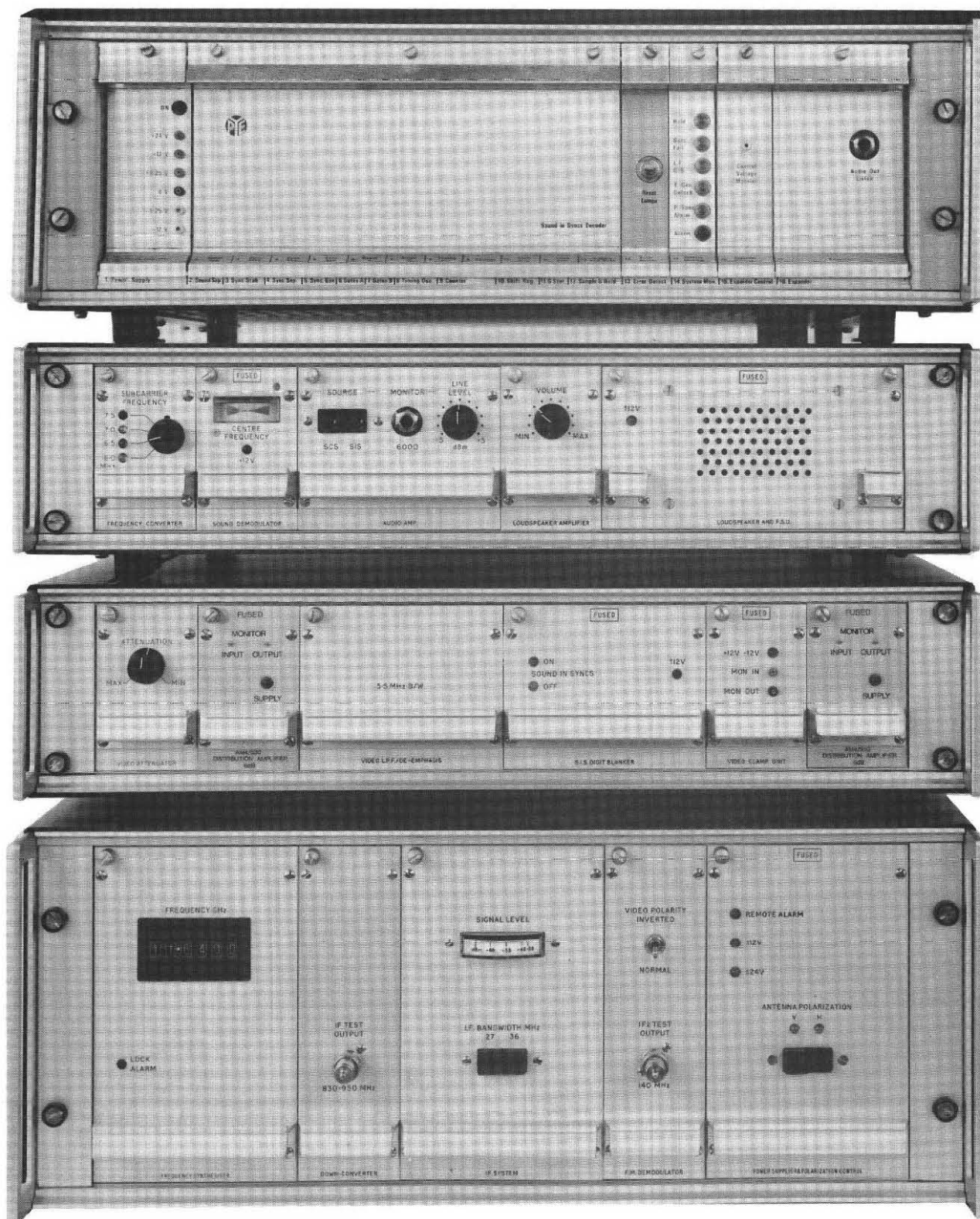


Fig. 9 — The indoor receiving equipment.

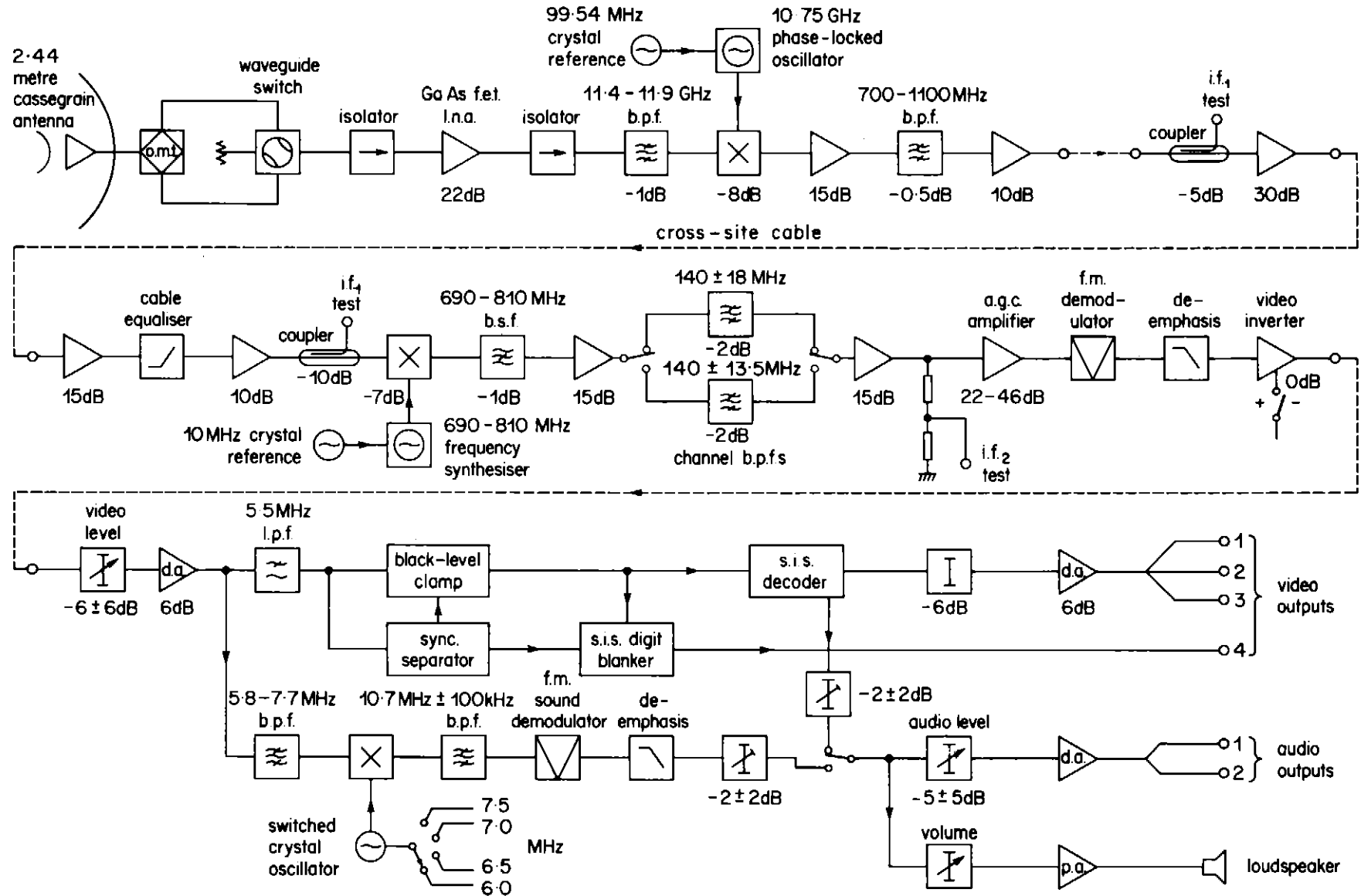


Fig. 10 - Block diagram of the receiver.

TABLE 2 : Radio frequency performance of the terminal

Receiver input noise temperature	$\leq 460\text{K}$, 11.5 – 11.8 GHz
Frequency response to i.f. ₁	$\pm 1.5\text{ dB}$, 700 – 1100 MHz
Frequency response to i.f. ₂	$\pm 0.7\text{ dB}$, 140 $\pm$ 18 MHz
Frequency response to i.f. ₂	$\pm 0.5\text{ dB}$, 140 $\pm$ 13.5 MHz
RF image rejection	$\geq 30\text{ dB}$, 9.6 – 10.1 GHz
IF image rejection	$\geq 25\text{ dB}$, 530 – 690 MHz
Demodulator linearity	$\pm 2\%$, 140 $\pm$ 18 MHz

TABLE 3 : Video performance of the terminal

2T pulse/bar ratio	95%
Chrominance/luminance gain inequality	–1 dB
Chrominance/luminance delay inequality	–8 ns
Chrominance/luminance crosstalk	+5%
50 Hz bar tilt	0%
Differential gain	8%
Differential phase	4°
Unweighted signal/noise ratio (5 MHz bandwidth)	36 dB
Picture quality (CCIR – 5 point scale)	Grade 4

with f.m. television signals was measured by establishing a link through the OTS, with the BBC Transportable Earth Station¹² providing the up-link. The up-link carrier/noise ratio (C/N) was around 20 dB with standard Eurovision operating conditions. The video performance with conventional PAL test waveforms is summarised in Table 3.

The received C/N ratio was not measured directly because a suitable filter of known noise bandwidth (to suppress the carrier in the receiver i.f. band) was not available. Therefore conclusions about the noise performance of the receiver had to be derived from the measured signal/noise ratio, after demodulation. The expected accuracy of this measurement was about $\pm 0.5\text{ dB}$.

Signal/noise ratios were recorded for cases higher up-link C/N . On occasions when the up-link was provided by the British Telecom Goonhilly earth station (8m antenna), the measured signal/noise ratio was 37.5 dB. In Appendix 10.2 a link budget calculation is presented for such a case, with an up-link C/N of 25 dB, and this indicates that the achieved G/T ratio was about 1 dB lower than the expected value. This discrepancy was probably caused by inaccuracies in the assessment of the waveguide system loss, the propagation loss and the antenna efficiency. Also, there is a possibility that the received signal/noise measurement was influenced by phase-noise and satellite a.m./p.m.-conversion factors, which were not covered by the simple link budget calculation (i.e. factors which could affect the relationship between the signal/noise ratio and

the relationship between the signal/noise ratio and the C/N).

In addition to the original requirement for reception of PAL-coded television signals, on several occasions SECAM-coded signals were successfully received and transcoded to PAL for inclusion in a television programme about satellite developments.

7. Further work

There are several ways in which the performance of the receiving terminal could be improved, and its facilities extended.

Improvements to the antenna could include:

- (a) a new main reflector with a more accurate surface profile and possibly larger diameter,
- (b) a new subreflector, manufactured from solid aluminium alloy, rather than plate; there were indications that the subreflector profile underwent small changes after fabrication as stress in the material dissipated. This could allow the inclusion of special shaping to increase the antenna efficiency, and
- (c) a motorised mount for the main reflector, to allow simple and rapid re-pointing of the antenna for reception of other satellites in the future. However, the limited frequency range of the receiver, as described, would mean that extensive modifications would be needed for the future receptions of, for instance, DBS satellite signals. Such a motorised mount could also be used to measure the radiation pattern of the complete antenna (around the main lobe).

Improvements to the receiver could include:

- (a) the provision of group-delay equalisers in the channel-defining i.f. filters, and
- (b) the acquisition of a higher performance, although undoubtedly more expensive, f.m. demodulator. The device used displayed short-comings when operating close to threshold, in that the bandwidth of its limiting amplifier appeared to vary.

8. Conclusions

A complete satellite receiving terminal has been described, for reception of f.m. television signals in the OTS down-link band. The equipment

has operated continuously without attention for a considerable period of time and has provided television and sound signals for experimental and demonstration purposes.

The performance of the terminal, although limited in some respects by financial and instrumentation constraints, has met design expectations and has proved to be adequate for its planned use.

The decision to make the receiver tunable provided a valuable facility in operational use, and the ability of the receiver to cater for various operating conditions increased the availability of usable television signals, for demonstration purposes, over that of some broadly equivalent commercially manufactured terminals.

In 1983, when the OTS was no longer available to carry television signals, the receiver was successfully converted with small modifications to operate within part of the ECS down-link band.

9. References

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10. Appendices

10.1. Standard operating conditions

The following modulation and receiver parameters are used on Eurovision links between satellite earth stations :

Bandwidth of f.m. channel	36 MHz
Video deviation sensitivity	25 MHz/V
Coupling of baseband signals (fed to the f.m. modulator)	AC
Sense of deviation	black to white corresponds to an increase in frequency
Pre-emphasis of video signal	to CCIR Rec. 405-1
Frequency of commentary subcarrier	7 MHz
Amplitude of commentary subcarrier	140 mV peak-to-peak
Amplitude of s.i.s. pulses	700 mV

For DBS a complete set of operating conditions has yet to be formulated, and the requirements of different countries will possibly be different. However, for simulation purposes, there are two parameters which were used in the 1977 WARC plan and can be assumed to be representative of future DBS systems:

Bandwidth of f.m. channel	27 MHz
Video deviation sensitivity	13.5 MHz/V

10.2. Link budget calculation

Data on the receiving terminal and the rest of the satellite link can be compiled in the form of a power budget to predict the received signal/noise ratio. The following example represents the case of the British Telecom Goonhilly earth station providing the up-link to the OTS transponder 4, with standard Eurovision operating conditions, 25 dB up-link C/N and 1.3 dB propagation loss in the down-link path. Notes on the derivation of the various figures will follow.

Quantity		Notes
Satellite saturated e.i.r.p. to beam centre	48.7 dBW	(i)
– Off-axis reduction to S.E. England	1.5 dB	(i)
– Isotropic loss	205.5 dB	(ii)
– Propagation loss	1.3 dB	(iii)
+ Receiving terminal G/T	19.0 dBK ⁻¹	(iv)
– Receiver noise bandwidth	76.0 dB Hz	(v)
– Boltzmann constant	228.6 dBW Hz ⁻¹ K ⁻¹	
= Down-link C/N	12.0 dB	(vi)
Up-link C/N	25.0 dB	(vii)
∴ Overall C/N	11.8 dB	(viii)
+ FM improvement	24.7 dB	(ix)
+ Pre-emphasis improvement	2.0 dB	(x)
= Unweighted video signal/noise ratio	38.4 dB	(xi)

Link budget notes

- (i) The OTS transponder 4 had a saturated output power of 13.2 dBW and the spotbeam antenna had an on-axis gain of 35.5 dB¹¹. London was on the –1.5 dB contour of the radiation pattern of this antenna.
- (ii) The isotropic loss (inverse-square law between two isotropic antennas) is given by $10 \log_{10} (4\pi R/\lambda)^2$, where R is the slant-path range to the satellite (38,584 km from London) and λ is the wavelength (25.8 mm at 11.64 GHz, the centre frequency of channel 4).
- (iii) The propagation loss has two components ; atmospheric attenuation and rain attenuation. Atmospheric attenuation is a function of the slant path elevation and was about 0.3 dB for the 30° elevation of the OTS from London. Rain attenuation is quantified statistically and depends on the geographical location of the receiving terminal. Taking the value exceeded for 0.1% of time, or 9 hours per year, for London, the rain attenuation is about 1 dB.

The total propagation loss is then 1.3 dB.

(iv) The receiving terminal G/T (figure of merit) is given by the following formula:

$$G/T = \frac{\alpha\beta G_r}{\alpha T_a + (1 - \alpha) T_0 + T_r}$$

- - - where α is the dissipative loss caused by the waveguide and feed system prior to the l.n.a. input,

β is the non-dissipative loss owing to errors in the alignment of the antenna (beam pointing and polarisation),

G_r is the net gain of the antenna after the application of all efficiency factors except α and β .

(α , β and G_r are expressed as power ratios).

T_a is the antenna noise temperature in Kelvins,

T_0 is the reference temperature, 290K,

and T_r is the receiver effective input noise temperature in Kelvins.

An estimated value of 0.89 (0.5 dB) is used for α , the main component of which is the loss in flexible waveguides (about 0.7 dBm⁻¹, typically).

The value of β was expected to be very low because the antenna alignment was checked prior to quantitative measurements, so a value of 1.0 (0 dB) is used.

The gain of a circular aperture antenna is given by $\xi(\pi D/\lambda)^2$, where ξ is the aperture efficiency, 60% or 0.6 estimated for this case, and D is the aperture diameter, 2.44m. A value for G_r of 52480 (47.2 dB) is used.

The antenna noise temperature has components owing to the main and sidelobes, at the sky noise temperature (75K, consistent with the 1.3 dB propagation loss in (iii)), and a component owing to other wide-angle lobes at the ground noise temperature T_0 (290K). The result for T_a is estimated as 96K.

For the input noise temperature of the receiver, the measured value of $T_r = 460K$ is used.

The resulting G/T has a value of 79.4, as a power ratio, or 19 dBK⁻¹, in decibel form (in clear weather, with 0.3 dB propagation loss, the result would be 19.4 dBK⁻¹).

It will be noticed that the formula used takes account of the noise contribution of the feed system loss, α .

- (v) Standard Eurovision operating conditions, summarised in Appendix 10.1, call for a f.m. peak-to-peak deviation of 25 MHz per volt of peak video signal at 1.512 MHz, the 0 dB point of the CCIR Rec. 405-1 pre-emphasis characteristic. Certain video signals such as s.i.s. and colour bars put considerable energy out at the extremities of the 36 MHz channel bandwidth, and consequently, to avoid undesirable truncation of the f.m. spectrum, a flat frequency response over the full 36 MHz is desirable. The Tchebychev (0.2 dB ripple) five resonator filter used in this receiver had a noise bandwidth (equivalent rectangular bandwidth) of 39.6 MHz, or 76.0 dB Hz.
- (vi) The down-link C/N assumes no contribution of noise from the up-link.
- (vii) An up-link C/N of 25 dB was typical for the Goonhilly/OTS combination.
- (viii) The overall C/N , at the demodulator input, combines the noise contributions of both up- and down-links and is given by $[(C/N_{up})^{-1} + (C/N_{down})^{-1}]^{-1}$, with all figures expressed as power ratios.

- (ix) The f.m. improvement relates the video signal/noise ratio (prior to de-emphasis) to the overall C/N and is a function of Δ , the f.m. peak-to-peak deviation given in (v), B , the receiver noise bandwidth (39.6 MHz), and f_c , the video cut-off frequency (5 MHz is used in conventional video noise measurements with BBC equipment). The f.m. improvement is given by $1.5 (\Delta/f_c)^2 . B/f_c$, as a power ratio.
- (x) The pre-emphasis improvement is the effect of the noise weighting applied by the de-emphasis characteristic to the triangular baseband noise spectrum generated by f.m. demodulation of the flat r.f. noise spectrum, up to f_c . It has a value of 2 dB.
- (xi) The final unweighted signal/noise ratio is the ratio of peak-to-peak picture signal (not including syncs.) to r.m.s. noise, in the band up to f_c .

If the orthogonally polarised transponder, $\bar{4}$, was used, the results would be very similar.

Another interesting case is the use of DBS modulation and receiver parameters to simulate a DBS system. The f.m. deviation would be 13.5 MHz, defined similarly to (v), and a 27 MHz bandwidth filter would be used in the receiver. If all other operating conditions remained as in the previous case, the results are predicted as follows:—

Overall C/N	13.4 dB
Unweighted video signal/noise ratio	33.1 dB

These correspond to the limit-of-service conditions assumed in the 1977 WARC plan for satellite broadcasting, which used a minimum overall C/N of 14 dB for 99% of worst month rainfall conditions, which translate to a minimum C/N of 13.3 dB for the 0.1% of time exceedence used in (iii).